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Soil and Water Conservation in the Agricultural Fields of Zambia: Improvement of Soil Fertility through the Use of "Planting Basins" and Soil Amendments by Rural Communities

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This study aimed to demonstrate the potential for improving yields of maize and other crops, as well as farm income, in vulnerable rural communities through moderate use of inputs, using a conservation farming technique called "planting basins," thereby improving food self-sufficiency. This technology improves soil fertility by adopting a low application rate of inorganic fertilizer and supplementing this with soil amendments based on animal manure and lime to improve soil nutrient levels. Nutrients and moisture both limit plant growth in semi-arid Zambia. The technique was tested with plow-layer soil samples collected from farm fields at Mungu and Chikupi. Before the addition of 100 kg/ha fertilizer (N : P : K 10 : 20 : 10), 100 kg/ha urea fertilizer, 300 kg/ha lime and 4,000 kg/ha animal manure, soil pH (H_2O) was 6.34 and 6.09 at Mungu and Chikupi, respectively, with corresponding pH ($CaCl_2$) values of 5.24 and 4.9 for the two sites. The pH values increased (improved) significantly (to 6.80 and 6.39 pH (H_2O) and 5.41 and 5.21 pH ($CaCl_2$), respectively; $P = 0.001$) in both soils after the addition of these soil amendments. The soil moisture content also rose from 2.37 and 2.68% in Mungu and Chikupi, respectively, to 7.91 and 7.30%. Available P also increased from 4.98 to 22.55 ppm at Mungu and from 4.63 to 34.11 ppm at Chikupi.Total nitrogen content also increased from 0.054% to 0.095% at Mungu and from 0.049 to 0.103% at Chikupi. Soil carbon content increased from 0.804 to 1.098% at Mungu and from 0.686 to 1.120% at Chikupi. Other plant nutrients (Ca, Mg and K) also increased, and most of the increases were significant. These results demonstrate that soil improvement can be achieved with reduced inputs by rural communities.

Key words: Planting basins, Soil fertility, Moisture content, Animal manure, Conservation farming technologies

1. Introduction

1.1 Background

Zambia is a tropical nation in southern Africa with 12 million inhabitants, 60% of whom are farmers. Agriculture is the main source of livelihood for more than 75% of the rural households in Zambia. The country's total land area is 750,000 km^2, of which about 420,000 km^2 potential agricultural land, with only 14% of the land used to grow crops. The country contains up to 42% of the water resources of southern Africa. Unfortunately, only 12% of this water is utilized for irrigation, mostly by commercial farmers (Kalinda *et al.*, 2003). Currently, 155,912 ha of land are irrigated and 32,189 ha is under surface irrigation and sugarcane covers 50% of this area. Of the latter area, 17,570 ha are irrigated by sprinklers, and wheat accounts for 68% of this area. Drip irrigation covers 5,628 ha; coffee accounts for 92% of this area. Small-scale farmers commonly grow their vegetables in seasonally rainwater saturated wetlands known as "dambos" over an area of 100,000 ha. These areas are equipped with small drains, impounded furrows that are blocked to prevent water loss, and shallow wells used for irrigating a

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wide range of vegetables during the dry season, from May to October. Some small-scale farmers use treadle pumps to irrigate a total of about 525 ha. Matlock (2007) estimated that more than 3,000 treadle pumps are in use. Zambia covers an extensive area, between 8°S and 18°S latitude and between 22°E and 33°E longitude; as a result, its climate ranges from semi-arid to semi-humid. The country's nine provinces include three distinct agro-ecological zones. These regions are defined on the basis of climatic characteristics of which rainfall is the dominant factor. Region III with the highest level of rainfall of between 1,000-1,500 mm covers the northern part of the country. The soils are leached due to the heavy rainfall the region receives. The soil types found in the region are haplic Acrisols. Region II with intermediate rainfall of between 800-1,000 mm is evenly distributed and good for crop production such as staple food maize crop. The soil types are clayey to loamy soils: Haplic lixisols, haplic Luvisols, haplic acrisols and other soil types (FAO, 1973). Region I with the least rainfall of less than 800 mm is the driest region and most prone to drought. Zambia has many bodies of water (such as the Kafue and Zambezi Rivers) that are largely unexploited; only 12% of its irrigation potential is currently being utilized (Kalinda *et al.,* 2003).

Soil and water are the two main natural resources that support both plant and animal life. Zambians must use these resources judiciously to ensure their survival and that of future generations. Soil and water are essential for ecosystem health, and must therefore be conserved. In addition to activities designed to improve and conserve soils, water harvesting is important so that citizens can collect, store, and conserve runoff to permit agriculture in arid and semi-arid regions (Boers and Ben-Asher, 1982). Many conservation practices have been promoted by Zambia's Ministry of Agriculture and Cooperatives (MACO) and partners such as the International Centre for Research in Agro-forestry (ICRAF), the Golden Valley Agricultural Research Trust (GART), the Conservation Farming Unit (CFU) of the Zambia National Farmers Union (ZNFU), and the Zambia Agricultural Research Institute (ZARI). These practices include conservation tillage, soil fertility improvement, and erosion control. Unfortunately, many of the outputs of these agencies, though technically sound, did not meet the needs of farmers. As a result, the practices have not been widely adopted because they were developed and tested in managed research trials without proper consideration of the problems and difficulties encountered by the smallholders who would be the ultimate beneficiaries of these technologies (Twomlov and Hove, 2006). As a result, new solutions that will be easier to adopt are needed.

Conservation tillage practices include reduced or minimum tillage, zero tillage, mulch tillage and strip tillage. Soil fertility practices focus on increasing nutrient levels in the soil using crop residues, crop rotation, improved fallowing, mulching, intercropping and the addition of manure from cattle, goats and chickens. Fast-track technologies such as early planting (simultaneously with the first rains) are being promoted to give an immediate response to the season's water, followed by "basin construction" using hoes and ripping of the soil using oxen-drawn plows. Combining crop rotation with conservation tillage increases the benefits of both practices. Erosion-control practices take the form of constructing control ridges (bunds and contour ridges), terracing, the installation of storm drains, and contour planting of vertiver grass (*Chrysopogon zizanoides*), (MACO and ORGUT, 2003).

In terms of judging the ability of the rainfall resource to meet farmer needs, it is assumed that the maximum water requirement for plant growth equals 50% of the potential evaporation of an open water surface. On this basis, plant growth is endangered when rainfall is less than 25% of the potential evaporation (GART, 2004b). All of region I and most of region II fall in this category, and in these regions, water conservation measures are crucial for the success of farming.

To take advantage of the available water, rainwater harvesting techniques are being promoted by Zambia's government through the Programme Against Malnutrition —Food Security Pack (PAM-FSP) and non-governmental agencies such as GART and ZNFU-CFU for collecting, storing, and conserving rainfall and surface runoff in semi-arid regions of Zambia. These range from the use of planting basins (a kind of basin used in conserving the soil and water by encouraging water infiltration and avoiding soil erosion) to the construction of dams that provide irrigation water outside the rainy season. Another important strategy for protecting the soil and replenishing water is the incorporation of agroforestry into the main agricultural production practices. This can also help to eradicate hunger, especially through the production of basic food and systems to feed the poor in disadvantaged areas. Based on the use of agroforestry methods, soil fertility can be replenished and degraded land can be regenerated (Ajayi and Matakala, 2007). Fertilizer-tree systems are now common in Zambia. These systems include improved fallows systems in which nitrogen-fixing species such as *Faidherbia albida* (locally known as the Musangu tree), velvet beans, and other crops are used to protect the soil and restore its fertility. This requires careful selection of species and agroforestry techniques and judicious management of limited available resources (Ajayi and Kwesiga, 2003). The government of Zambia and the international donor community has begun promoting a new package of agricultural technologies as a viable way of improving the livelihood of vulnerable rural communities. This work has been done by a number of organizations such as ZNFU's CFU and GART, with the initial goal of alleviating poverty and improving the welfare of the smallholder farmers in the country (Haggblade and Tembo, 2003; CFU, 2007).

Despite the work that has been done to demonstrate the advantages of conservation farming, the adoption of conservation practices has been slow because farmers focus on short-term consumption and sales; when the benefits are not immediately obvious and become beneficial only in the long run, the benefits must clearly outweigh the short-term drawbacks (Kiome and Stocking, 1993). If, for example, crop production decreases in the short term, farmers will re-evaluate the overall benefits of adopting new practices even if the potential long-term benefits are clear. Chomba (2004) stated that land and water for agriculture are scarce natural resources, and that the promotion of good land management has thus taken center stage in Zambia. Factors that could be associated with the adoption of conservation farming practices are being considered so that farmers can choose among multiple practices and adopt bits and pieces of a given technology. Extension services should be concentrated in areas that are accessible and where the new techniques and technologies can be most easily adopted, and local infrastructure should be improved to minimize the costs of delivering extension services and agricultural inputs to those who need them most.

ZNFU's CFU assists smallholder farmers to adopt more productive and environmentally sustainable conservation farming systems that increase yields, enhance food security, mitigate the effects of drought, improve soil fertility, and reduce the effects of conventional farming tillage practices such as crop residue burning and ploughing the land late exposing it to soil erosion that are undermining the agricultural resource base and contributing to poverty and rapid deforestation. CFU has been supported by the Norwegian Agency for Development Cooperation, the Swedish International Development Cooperation Agency, Dunavant Cotton, and Zambia's Ministry of Agriculture.

1.2 Previous Studies

Haggblade and Tembo (2003) estimated that between 70,000 and 120,000 small-scale farmers had adopted conservation agriculture by 2003, which amounts to about 10% of the smallholders in Zambia. The initial planting basin concept (discussed in section 2.1 of this paper) was proposed by Oldrieve (1993), for use by small-scale farmers in Zimbabwe in the late 1990s. Odreive's initiatives in Zimbabwe pioneered the concept of conservation farming, and Zambians subsequently adopted these technologies and modified them to suit local conditions. Modification continues as a result of ongoing research by stakeholders such as GART, CFU, ZARI, the Programme Against Malnutrition's Food Security Pack, the Cooperative League of the United States of America, the SIDA's Soil Conservation and Agroforestry Extension, the FAO's World Agroforestry Centre, and Dunavant Cotton.

1.3 Basic Information on the Study Area

1.3.1 Location of the study area

The two sites used in the present study (Mungu and Chikupi) are located in the southeastern part of Kafue District in Zambia's Lusaka Province, in the Kafue River basin. Mungu and Chikupi are 7 and 14 km, respectively, from Kafue town (Fig. 1;

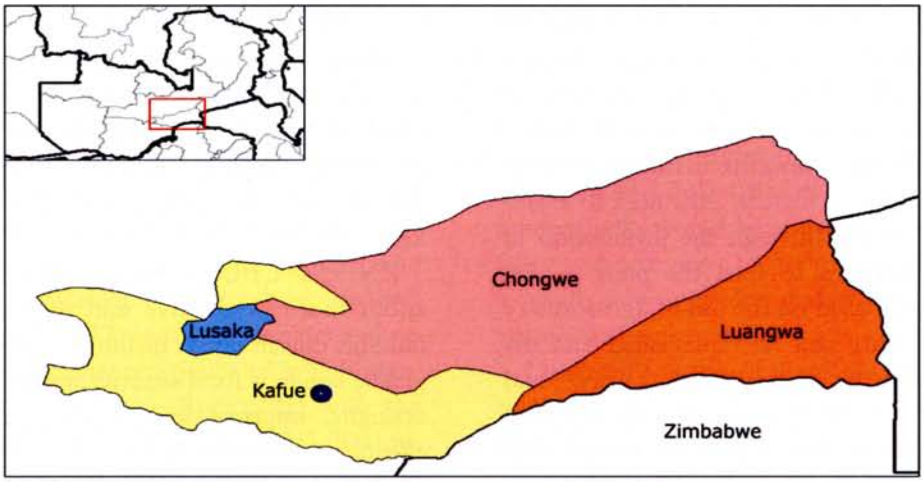

Fig. 1. Map of Lusaka Province showing the location of Kafue District.

KDC, 2006).

1.3.2 Climate and topography of the study area

Zambia's topography comprises three main land types: mountainous areas, high plateaus, and low valleys. Zambia and Zimbabwe share the man-made Lake Kariba, which was built to generate hydroelectric power. In the north, on the border with the Congo Democratic Republic, lies an area rich in minerals, especially copper, cobalt and emeralds. Due to its relatively high altitude ranging between 900 and 1,600 m above sea level, Zambia's climate is seldom unpleasantly hot. There are three distinct seasons:

A. a cool and dry season from May to August, when temperatures range from 14 to 26℃ during the day and 6 to 25℃ at night.

B. a hot and dry season, from September to November with temperatures as high as 17 to 35℃; and

C. a warm and wet season from December to April from 14 to 30℃

The country's primary vegetation is savannah, with areas of tropical grassland and woodland that include a variety of grass and tree species. Several seasonally flooded areas exist in flat swampy and marshy plains, such as the Kafue flat and the Bangweulu and Lukanga swamps.

Kafue has two agroecological regions: a plateau (region IIa) with rainfall range between 800 to 1,000 mm and a valley demarcated by hills (region I with rain fall less than 700 mm), which covers about 250 km^2. The dominant soil types in Kafue are acrisols and vertisols, with granite as parent materials (KDC, 2006). In the context of agriculture, soil properties are crucial, because they determine nutrient availability to plants. Of these properties, pH is particularly important, because most of the country's soils are acidic, and this can reduce nutrient availability.

1.3.3 Rainfall patterns in the study area

The rainfall pattern is a dominant force that defines the agroecological zones of the study area. Zambia has three agroecological zones: The highest amount of rainfall (1,000 to 1,500 mm/year) is received in region III, in northern Zambia, and the lowest amount (400 to 700 mm/year) is received in region I, in southern Zambia. region II, which lies between regions I and III, sometimes experiences mean rainfall of less than 800 mm/year, leading to drought that causes low crop productivity (Tiffen and Mulele, 1993). The amount of rainfall (Fig. 2) ranges from 400 to 700 mm/year in the lowlands (the valley in the Chiawa area of Kafue), but increases to between 800 and 1,000 mm/year in the plateau of Kafue.

1.3.4 Soil and water resources of the study area

The Zambezi and Kafue rivers are the main rivers in Zambia. The Kafue River flows almost entirely inside Zambia and become a tributary of the Zambezi River, which flows through many countries (e.g., the Congo, Angola, Namibia, Botswana, Zimbabwe, and Mozambique) before it reaches the Indian Ocean. Unfortunately, these

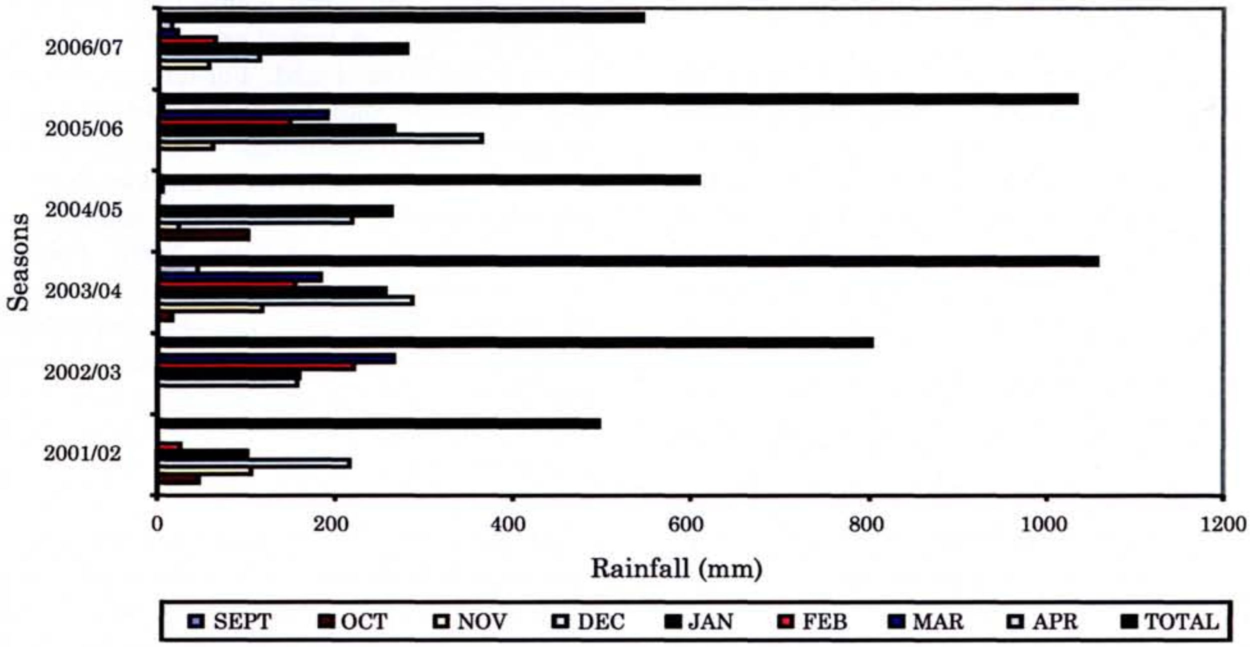

Fig. 2. Rainfall data from 2001 to 2007 in Kafue District.

rivers are only used for hydroelectric power and very little of their water is withdrawn for irrigation.

1.3.5 Current situation in the study area

One common problem with practicing conservation agriculture relates to continuity: the new agricultural practices often stop being used soon after the end of the project. This may result from withdrawal of the incentives provided during the project or poor articulation of the sustainability component of the new practices. This leads to drudgery in the implementation of activities intended to provide water to crops and protect or restore soils. Utilization of water resources other than rainfall is currently very low, as is clearly shown by the lack of the irrigation facilities along rivers. In addition, inappropriate farming methods that reduce biodiversity or interfere with its conservation have promoted deforestation and reduced the vegetation cover. This can further reduce the availability of water due to increased evaporation from bare soils. The soil in Zambia has also been rendered infertile in many areas due to overuse, resulting in low crop yields and increasing soil erosion. To restore this soil's productive capacity, organic matter and inorganic fertilizers must be provided, but these materials are not affordable for many farmers. Unpredictable weather conditions have often exacerbated the problem. In some years, there have been both floods and severe drought, both of which reduce food availability.

A wide range of crops can grow in Zambia due to the diversity of climatic conditions. Zambia's high altitude plays a significant role in agricultural production. Some locations are very low and hot, and crops that prefer higher temperatures do well in such environments. Conversely, at high altitudes, crops adapted to cool temperatures are grown. Maize is Zambia's main staple food. This crop is ground into a powder, which is cooked into a hard porridge locally known as *nshima,* and served with meat, fish and vegetables. Other important crops include sorghum, millet, and cassava, which are also used to create *nshima.* Several varieties of beans are served together with groundnuts, cowpeas and soybeans, and many other vegetables, cotton, and tobacco are grown as cash crops. Many widows find themselves unable to farm and are among the most impoverished citizens, often barely able to survive. These women belong to the group of farmers that are the most important targets for education about low-input soil and water conservation technologies.

1.3.6 Relevance of soil and water resources conservation

No one can farm without sufficient water for their crops and livestock, or without sufficient high-quality land that can support these crops and animals. Practices that lead to loss of soil, such as deforestation and erosion of productive top soils through unsustainable farming practices, should be stopped to avoid further soil degradation. Improving the infiltration of water into the soil (e.g., by reducing runoff) should also be promoted because this process replenishes underground water reservoirs and promotes both current and subsequent vegetation growth.

1.4 Purposes of the Study

Based on the preceding background, the aims of the present study were as follows:

I. To show that soil quality can be improved through the use of planting basins where soil amendments such as animal manure and the growth of nitrogen-fixing plants (such as velvet beans) are used, thereby improving nutrient availability to plants, crop yields, and food self-sufficiency for vulnerable farmers.

II. To use rainwater more efficiently, thereby increasing the moisture content of the soil.

2. Materials and Methods

2.1 Planting Basins

Planting basins have many names. For example, in Zambia, they are associated with "potholing" and conservation-farming basins (Baudron *et al.*, 2007). These are structures roughly 30 cm long, 15 cm wide and 15 to 20 cm deep. In the context of this study, a "planting basin" is created by digging a hole (the basin) below the level of the surrounding land, and refilling it with the top 20 cm of the soil (the most fertile part) backfilled to a level 3-5 cm below the surrounding surface, so that rainfall will be collected and channeled towards the plants. Inorganic fertiliser such as Compound D with N : P : K 10 : 20 : 10, Urea and Soil amendments such as lime and animal manure are then added to the basins to improve its properties and its ability to support plant growth. They are dug after harvesting field crops, following a precise grid of 15,850 planting basins per ha. Plants are spaced at 90 cm between rows and 70 cm within rows (Twomlov and Hove, 2006). A typical preparation operation covers 0.5 to 1.0 ha of land. For farmers who own draft animals, ripping of the soil with a plow or similar device is recommended to facilitate the creation of the planting furrows by breaking the hard pan and encourage water infiltration and moisture retention (Norin and von Essen, 2005). Preparation is recommended to start in the dry season to spread the work over a long period (3 to 5 months) from April to August. Late preparation is more difficult because the ground surface hardens. The planting basin approach is designed to be as simple as possible to make it easy for even impoverished farmers to implement:

(a) Seeds are sown in simple pits that are excavated with hand hoes, without the need to plow the fields. This allows people without draft animals to plant their crops early without waiting for the rains, as farmers who own oxen can do. Velvet beans (*Mucuna pruriens*) should be incorporated as both a nitrogen fixing plant and cover crop to help fight the weeds by its conopy. It should be planted a seed rate of 20 kg per ha. The beans should be planted one month after planting maize to avoid competing with maize due to its vigorous vegetative growth. To prepare the land, farmers require a "teren" rope to ensure accurate spacing of the basins, one or more strong hoes, two 90 cm tall sticks to help maintain the spacing between rows, two pegs to hold the ropes when they are stretched across the field, and cups or aluminum drink cans to measure fertilizer amounts. (b) The 15 m long (or longer depending on field length and preference) teren rope has bottle tops attached at 70 cm intervals, which mark the position of the center of each basin.

2.2 Soil Analysis

Soil samples (200 g) from the plow layer (to a depth of 20 cm) were collected using a small shovel at 16 points in the field 10 m apart at both study fields (Mungu and Chikupi). The total weight from each field was 200 g multiplied by 16 resulting in 3,200 g and the samples at each site were combined and homogenized. Only 500 g was taken per each sample for analysis. These two sites were chosen by selecting farmers who had successfully used the planting basin approach to produce a good

Table 1. The soil amendments and fertilizer applications used in this study

	Description	Measuring tool for use by farmers	Application amount/0.25 ha
1	Manure (cattle and goat)	Two Coca cola drink cans (each about 350 ml/basin) 1 scotch cart/0.25 ha is 1000 kg	1000 kg
2	Fertilizer	No. 8 fertilizer cup/basins	25 kg Compound D (N : P : K 10 : 20 : 10) as basal fertilizer, and 25 kg (urea) as top dressing
3	Lime	No. 8 fertilizer cup/basins	300 kg

crop. Each site covered a total of 0.25 ha. Soil samples were sent to Japan's Tsukuba University for analysis of the nutrient status of the two soils. The sampling was done at two different times. The initial sampling was done before addition of inorganic fertilisers and soil amendments at the beginning of the rainy season and the other sampling after the rain season. This was to see the effect plant interaction and status of soil quality factors such as soil pH after 5 months. In this study, farmers applied inorganic fertilizer, urea, lime, and animal manure to their fields at the concentrations summarized in Table 1.

2.3 Experimental Design and Statistical Analysis

Two sites, Mungu and Chikupi were sampled from a 50 m × 50 m field. A total of 16 points at 10 m apart from each field. These were homogenized and two 500 g samples finally collected for testing. R-regression using t-test was used to analyze the data indicated in Table 2.

3. Results and Discussion

3.1 Available Phosphorus

At both Mungu and Chikupi, available P was significantly higher after addition of the soil amendments (Tables 2 and 3). The addition of fertilizer and animal manure increased available P to more than four and seven times the original values at Mungu and Chikupi, respectively. From the standard available P requirements, the levels before addition of fertilizers and soil amendments were low for both Mungu and Chikupi 4.98 and 4.63 ppm. The available P improved to 22.55 and 34.11 ppm for Mungu and Chikupi which is categorized as high from the standard requirements. In addition, the final levels of available P at the two sites did not differ significantly between sites, suggesting that the same level of nutrient inputs can be applied at both sites.

3.2 Total Exchangeable Bases and Cations

The mean exchangeable base contents increased significantly at both Mungu and Chikupi (Tables 2 and 3) after the addition of fertilizer and animal manure. The totals increased by roughly 50% at Chikupi and by nearly 300% at Mungu. The cation exchange capacity increased significantly at both Mungu and Chikupi (Tables 2 and 3), but did not differ significantly between the sites.

3.3 Carbon Content

Soil carbon contents increased significantly at both Mungu and Chikupi (Tables 2 and 3).The carbon content at Chikupi increased by 40% and Mungu by 30%. Since the soils are low in organic carbon, this has shown tremendous improvement.

3.4 Moisture Content

Moisture content increased significantly at both Mungu and Chikupi (Table 2), but the two sites did not differ significantly. Based on these results, the two sites do not require different treatments to improve soil moisture. The rise in moisture content can be attributed to application of animal manure. As organic carbon rises, the moisture content rises as well.

3.5 Total Nitrogen

Nitrogen contents increased significantly at both Mungu and Chikupi (Tables 2 and 3), but did not

Table 2. Analysis of the statistical significance of the changes in soil properties in response to the fertilizers and soil amendments for the Mungu and Chikupi study sites

	Mungu Soils				Chikupi Soils			
	*Before	*After	*t*-statistic	*P* value	*Before	*After	*t*-statistic	*P* value
Available P_2O_5 (Truog) ppm	4.98	22.55	10.64	0.0087	4.63	34.11	6.65	0.022
pH (H_2O)	6.34	6.8	28.46	0.001	6.09	6.39	30.00	0.001
pH ($CaCl_2$)	5.24	5.41	Nan	0.001	4.9	5.21	30.00	0.001
Exchangeable Calcium ($cmol_c$/kg)	9.91	23.25	145.55	4.72e-05	5.61	10.42	14.02	0.005
Exchangeable Magnesium ($cmol_c$/kg)	1.73	8.04	96.02	0.0001	4.27	4.3	0.42	0.718
Exchangeable Potassium ($cmol_c$/kg)	0.11	0.23	23	0.0018	0.13	0.45	65	0.0002
Exchangeable sodium ($cmol_c$/kg)	0.03	0.04	0.832	0.4929	0.02	0.08	11	0.0082
Cations Exchange Capacity ($cmol_c$/kg)	12.61	31.02	39.93	0.0006	12.7	15.88	33.29	0.0009
Moisture content %	2.37	7.91	47.95	0.00063	2.68	7.3	23.1	0.0019
Total Nitrogen %	0.054	0.095	23.02	0.0018	0.049	0.103	13.27	0.0056
Carbon %	0.804	1.098	24.9	0.0016	0.686	1.12	13.97	0.0051
C/N	14.89	11.48	−14.35	0.0048	14	10.88	−11.4	0.0076
Total Exchangeable Bases ($cmol_c$/kg)	10.04	15.26	114.22	7.663e-05	11.06	31.57	12.86	0.006

*Before and after application of soil amendments described in Table 1.

Table 3. Recommended soil nutrient values in agricultural soils (Loganathan, 1987)

Nutrients	Very low	Low	Moderate	High	Very high
N (Total N%)	<0.05	0.05-0.15	0.15-0.20	0.20-0.30	>0.30
P (Available P, Bray and Kurtz No 1, ppm)	<3	3-10	10-20	20-30	>30
K (exchangeable K, meq/100 g)	<0.2	0.2-0.3	0.3-0.6	0.6-1.0	>1.0
Ca (exchangeable Ca, meq/100 g)	<2	2-5	5-10	10-20	>20
Mg (exchangeable Mg, meq/100 g)	<0.3	0.3-1	1-3	3-8	>8

differ between the two plots. Thus, the two sites do not require different treatments to improve soil nitrogen availability. The nutrient status for Total nitrogen improved from very low to low compared with the standard requirements.

3.6 Carbon to Nitrogen (C/N) Ratio

The C/N ratio decreased significantly at both Mungu and Chikupi (Tables 2 and 3), but did not differ between the sites. The addition of organic materials to the soils through animal manure and the subsequent continuous decomposition of these materials increased the cation exchange capacity and led to high accumulation of nitrogen in the soils.

3.7 Exchangeable Magnesium Calcium and Potassium

Mg levels increased significantly at Mungu but not at Chikupi, whereas Ca and K levels increased significantly at both sites. Levels of exchangeable K and Ca nonetheless remained at low to moderate levels compared with the recommendations of Loganathan (1987), which are summarized in Table 3.

3.8 Exchangeable Sodium

Exchangeable Na levels increased at both sites, but the increase was only significant at Chikupi (Tables 2 and 3). The resulting values at both sites were lower and compared to recommended soil levels. However, since Na is generally considered a problem in soils (it is not a significant plant nutrient), its presence in a soil indicates undesirable salinization,these low levels are a good sign: they indicate that the soil amendments did not damage soil properties. A soil is considered sodic when the Exchangeable sodium percentage (ESP) is 6% or greater. ESP is calculated as follows: ESP = Exchangeable $((Na)/(Ca+Mg+K+Na)) \times 100$. For these particular soils, the ESP was lower than 6% before and after addition of fertilizers and soil amendments. It was less than 0.3% in both cases of Mungu and Chikupi soils; this does not interfere with plant growth.

3.9 Crop Yields

In addition to the soil samples, we compared crop growth in the planting basins with crop growth in eight districts of Zambia from 2004 to 2006 in fields managed using conventional cultural practices (i.e., plowing). The basins provided higher crop yields in all years (Table 4), except the 2004-2005 season due to drought occurrence (data not shown). This result confirms the finding of Haggblade and Tembo (2003) and Twomlov and Hove (2006), who reported that crop yields increased significantly due to the addition of fertilizer and animal manure in conservation agriculture practices.

Table 4. Crop yields under different fertilizer application rates

Crop	Basal		Top Dressing		Yield
	D compound N : P : K 10 : 20 : 10 kg/Ha	No. 8 Cups/Basin	Urea kg/Ha	No. 8 Basins	(t/ha)
Maize	100	1	100	1	3.5-4.5
	200	2	200	2	5.0-6.0
Sunflower	100	1			1.0-1.5
	200	2			2.0-2.5
Soybeans	100	1			1.0-1.5
	200	2			1.5-2.0
Groundnuts	100	1			1.0-1.5
	200	2			1.5-2.5

Values have been extrapolated to 1 hectare for easier comparison with the yields of the experimental study area.

3.10 Cost-Benefit Analysis

Although crop yields clearly improved using planting basins approach combined with the soil amendments described in this paper, it will be necessary to perform a cost-benefit analysis to determine whether the increased crop yields observed in the present study are sufficient to offset the increased costs (i.e., payment for inorganic fertilizer, lime, manure, velvet beans and the associated labour cost). A cost-benefit analysis would highlight the impact of the cost increases incurred by farmers in terms of labor, agricultural inputs (i.e., purchasing fertilizer, lime and manure), and the implementation of soil and water conservation measures. Loss of nutrients would represent an additional cost, whereas the retention of soil nutrients and water conservation would count as benefits in addition to the increase in crop yield. For the approach described in this paper to be sustainable, farmers will have to perceive a sufficiently high benefit to justify the additional labor and additional costs required to implement this approach.

4. Conclusions and Recommendations

The results of this study show that soil fertility and crop yield were improved by the application of soil amendments (lime, urea and animal manure) and in addition to the use of conventional inorganic fertilizer. The use of low-input technologies such as planting basins and other conservation farming practices thus appears to be a good way to mitigate poverty in vulnerable farming communities. The Zambian institutions involved in promoting conservation farming should use the results of our study to train farmers in the proper use of these technologies and to convince the farmers of the ongoing benefits of these technologies for the farmers. Community-based organizations and outreach schemes should also play important roles in educating farmers and other rural residents, including local leaders, about the benefits of conservation practices, thereby training more farmers in good land husbandry.

Based on the Zambian experience, there is urgent need for investment in conservation farming. Zambia's MACO, in collaboration with the Ministry of Community Development and Social Services, under the Programme Against Malnutrition's Food Security Pack, and the National Fertiliser Support Program, are potential sources of funding to expand this program to other farmers. The Japan International Cooperation Agency is expected to facilitate the work by providing logistical support and agricultural inputs, where necessary and in the development of an incentives framework to encourage farmers to improve their food security, alleviate rural poverty, and protect the environment. Technologies such as the use of planting basins will serve as a practical, low-cost, easy-to-implement way to change current farming systems and improve the livelihood of farmers.

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